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# ON THE CLASSIFICATION OF COMPRESSOR, PUMP OR ENGINE DESIGNS USING GENERALIZED LINKAGES

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## ABSTRACT

Starting with Wankel's classification of volume changing devices that are suitable for positive displacement type compressors, pumps or engines it is argued that other ways of classifying should also be explored. As a possible useful classification aid, the concept of generalized linkages is proposed. Using examples, it is illustrated how this concept aids the designer in obtaining inversions of basic mechanisms and variations of mechanisms.

## INTRODUCTION

Positive displacement compressors, pumps, and engines are mechanisms that produce volume changes. Some of these mechanisms have been around for a long time. The reciprocating piston device dates from the prechristian era and the rotary vane mechanism was invented by Ramelli in the 16th century. Later, especially in the 19th and 20th century, many more basic devices were added. As of now, there are more than one hundred different basic mechanisms that can be used to change volumes and are therefore suitable for compressor, pump or engine applications. It is, therefore, important to classify these devices in some orderly fashion. Classical texts in compressor, pump or engine design have so far failed to do this. Typically, they discuss the reciprocating piston, two or three rotary vane mechanisms, perhaps one odd device depending on the preference of the particular author, and perhaps lately also the Wankel rotary piston mechanism. Wankel, being a professional inventor, recognized this lack of information and compiled a collection of volume changing mechanisms, at first for his own use. He classified the mechanisms according to a scheme which seemed to him logical at the time, and finally published his classification in 1963 [1]. Wankel's classification is still the only systematic attempt, to the knowledge of the authors, to bring order into the wide variety of devices.

In the following, Wankel's classification is summarized and it is suggested, as an additional classification tool, to use the generalized linkage

concept [2]. It is felt that this concept will make it easier to recognize inversions of mechanisms, or mechanisms that do look like a new invention but are really an old concept in disguise. The generalized linkage concept can also be an aid to inventiveness.

## WANKEL'S CLASSIFICATION OF COMPRESSOR AND ENGINE MECHANISMS

In 1963 Felix Wankel published a book in which he classified rotary piston machines in a manner he felt would lead to a complete classification [1]. The rotary piston machines (ROPIMA) were divided into three distinct groups determined by the mode of motion of the center of gravity of the moving parts. They are as follows:

### Single Rotation Machines (SIM)

All of the moving parts rotate at uniform angular velocities about their own center of gravity since Wankel does not consider elliptical gears. (Figure 1a).

### Planetary Rotation Machines (PLM)

All the moving parts rotate at uniform angular velocities, plus at least one member moves in a constant planetary orbit. (Figure 1b).

### Rotating Piston Machines (ROM)

The moving parts rotate at variable angular velocity or variable planetary velocity. No Figure shown.

Wankel subdivided the basic groups into groups determined by the way the working chambers are formed. They are as follows:

- 1) Reciprocating engagement  
Where there is relative linear motion of the engaging (working) components. In Figure 2a this is the motion between link 3 and link 4.
- 2) Arcuate engagement  
The engaging components move in parallel

circular arcs. In Figure 2b, link 3 and link 6 form the working chambers and the dashed lines indicate the finite displacement of the working parts.

### 3) Intermeshing engagement

Relative motion between the working components is caused by a gear train and there are points on the working components that have zero relative velocity.

- a) Internal axis, the component with the smaller diameter also has fewer lobes and rotates at a higher R.P.M. than input crank. In Figure 2c the crank is link 3 and the rotor is link 2 and the working chamber is formed outside of the input and rotor axes.
- b) External axis, the engaging component with the higher R.P.M. has the fewer number of lobes. In Figure 2d, link 3 is the crank and link 2 is the rotor and the working chamber is formed between the input and rotor axes.

### 4) Slip engagement

The relative motion between the working components is caused by a gear train and there are points on the working components that have zero relative velocity.

- a) Internal axis, the engaging component with the smaller diameter has its R.P.M. less than the input crank and it has the greater number of lobes. In Figure 2e, link 2 is the rotor and link 3 is the crank. The working chamber is formed outside of the input and rotor axes.
- b) External axis, it is the same as the cam engagement external axis.

For a given gear train and input crank velocity the rotor in the intermeshing engagement has higher angular velocity than that of the slip engagement.

### 5) Counter engagement

The relative motion between the working components is caused by a gear train and there are no points on the working components that have zero relative motion. (Figure 2f).

This classification allowed Wankel to look for combinations that were not invented yet, "missing links", so to speak. He was able to fill a few of these empty slots, since what is today known as the Wankel engine or compressor is only one of his many inventions in this area. Some slots he was unable to fill by an invention of his own, but he felt that a mechanism of this classification could be invented. Some combinations he eliminated, since he concluded that they were impossible. Some of Wankel's conclusions about the possibility or impossibility of certain combinations are not shared by the authors.

## COMPRESSORS AND ENGINES AS GENERALIZED LINKAGES

The authors feel that although the classification presented by Wankel presented some order, that classifying mechanisms on how the center of gravity moves is not the only approach. They propose to reduce the mechanisms to their simplest form and show how different type pumps have the same basic kinematic building blocks where all mechanisms are represented by links and pin joints. For example, the single vane rotary compressor in Figure 3a can be reduced to a slider crank as follows. The vane, link 3, acts like a piston sliding in link 2. The sliding and rotating action of link 3 on the ground, link 1, can be replaced by another link pinned to 3 and to 1 [2]. A simple example of this is in Figure 3b. Since we want only pin joints and sliding surfaces we replace the circular pin at A with a block and a pin joint, Figure 3c. Since we added a block at A this now adds a link. Link 2 is pinned to ground and now the single rotary vane compressor becomes the familiar slider crank in Figure 3d.

When this approach is used on the rotary pump in Figure 4a it can be reduced to the two piston pump in Figure 4b.

Another example is the intermeshing engagement, internal axis pump/engine in Figure 5a. The gear train is examined first. Since link 2 (Rotor) rolls on link 1 (housing) two degrees of freedom are destroyed. This rolling contact can be replaced by a pin joint connecting link one to two. Link 3 (crank) is pinned to link one and to link two. The gear train now reduces to the three link structure in Figure 5b.

Since the rotor tip and gear train generates the hypotrochoid shape there could be clearance between the housing and the rotor and pumping action could take place. This leaves us with a structure as a generalized linkage. If there are no seals but the rotor contacts the housings the generalized linkage is Figure 5c. The point of contact between the rotor and the housing is replaced by a link and two pin joints.

For the case where seals are used the generalized linkage is Figure 5d. Figures 6a, b, c, d are examples of rotary compressors and their generalized linkages. It can be seen that as the number of lobes increase the basic gear train remains unchanged and links and pin joints are simply added. Now we respecialize some generalized linkages.

Example 1. The generalized linkage shown in Figure 5d.

- STEP 1: Link 1 is chosen as the frame.
- STEP 2: Links 1, 2, and 3 are chosen as a planetary gear train.
- STEP 3: Links 6 and 7 are chosen to have straight sliding contact with the frame.
- STEP 4: Point contact between link 2 and link 6 is chosen so links 4 and 5 are removed.

One example of a mechanism that exhibits the above characteristics is illustrated in Figure 7a.

Another possibility is to use steps 1 and 2 and change step 3 as such.

STEP 3: Links 6 and 7 are chosen to be pinned to ground.

STEP 4: Is left unchanged.

An example of a possible mechanism is illustrated in Figure 7b.

Example 2. The generalized linkage shown in Figure 8a.

STEP 1: Link 1 is chosen as the frame.

STEP 2: Link 2 is chosen as the input.

STEP 3: Links 3 and 4 are chosen to have sliding contact between them, and link 4 is pinned to ground.

STEP 4: The pumping action will be between links 4 and 1.

An example of this mechanism is illustrated in Figures 8b and c.

Example 3. The generalized linkage shown in Figure 9a. The linkage has zero degrees of freedom.

STEP 1: Link 1 is chosen as the frame and link 2 as the input.

STEP 2: Links 3 and 4 are chosen such that links 1, 2, 3 and 4 are a crank-rocker.

STEP 3: Sliding contact is chosen between 5 and 1 and since there are zero degrees of freedom, link 5 will follow a circular path on link 1.

An example of a mechanism that exhibits the above characteristics is illustrated in Figure 9b.

Example 4. The generalized linkage in Figure 9c. The two tertiary links are not pinned together as in Figure 9a, and it has zero degrees of freedom also.

STEP 1: Link 1 is chosen to be the frame and link 2 as the input.

STEP 2: Sliding and rotating contact was chosen between links 1 and 3 so links 4 and 5 were removed. The pumping volume is between link 1 and 3.

An example of a mechanism that exhibits the above characteristics is illustrated in Figure 9d.

It is important to realize the type of gear train used or which link became the frame was completely arbitrary. The designer can vary gear trains, substitute pin joints for sliders or replace a link with a single-contact joint and "invent" many mechanisms that don't resemble each other but have the same generalized linkage.

It is felt these few examples illustrate to a sufficient degree the potential usefulness of a generalized linkage classification.

#### DISCUSSION

This paper was motivated by the need to classify in some orderly fashion the more than 100 basic devices that can be used as compressors, pumps, or engines. For the purpose of general background, Wankel's classification was summarized first. Next, the concept of generalized linkages was

suggested as an additional classification aid. It is felt that the generation of a generalized linkage diagram will allow easier recognition of mechanism inversions, will allow recognition of mechanisms that look like new inventions but are identical to a mechanism already known, and will in general stimulate inventiveness.

The examples used were on purpose somewhat unusual and are perhaps not feasible from an economic viewpoint. It is left to the reader to use generalized linkages to come up with useful designs that are also novel.

Future work will have to consist of examining all known devices from the generalized linkage point of view and possibly other kinematic concepts, and of reclassifying them. To what extent features of Wankel's scheme of classification will be preserved is not known at this time.

#### REFERENCES

- [1] Wankel, F., Rotary Piston Machines, London Iliffe Books, London, 1963.
- [2] Ham, C. W., Crane, E. J., Rogers, W. L., Mechanics of Machinery, McGraw-Hill 4th Edition, New York, 11-13, 1958.

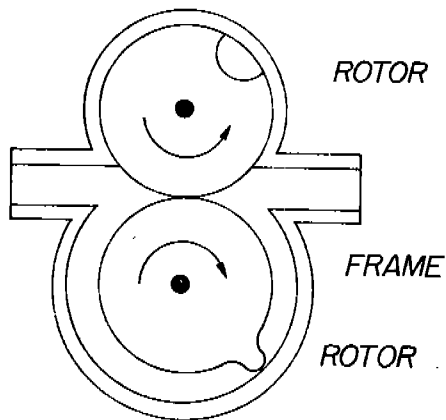


Figure 1a: Single rotation machine.

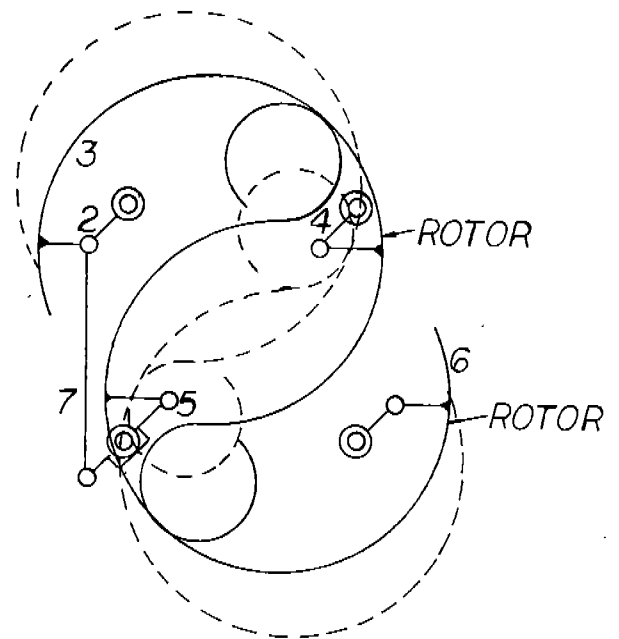


Figure 2b: Arcuate engagement.

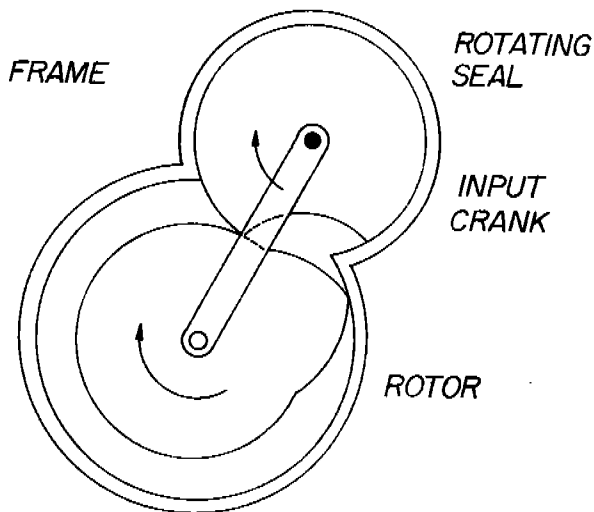


Figure 1b: Planetary rotation machine, input crank and seal rotate about point A. The solid circle ● is fixed to ground (frame).

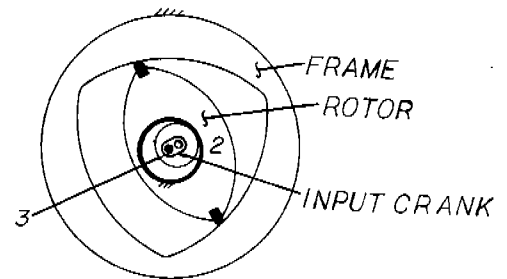


Figure 2c: Intermeshing engagement internal axis. The ring gear is fixed.

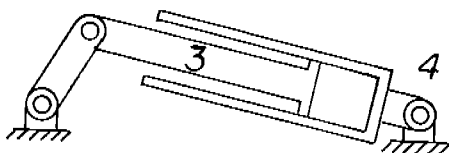


Figure 2a: Reciprocating engagement.

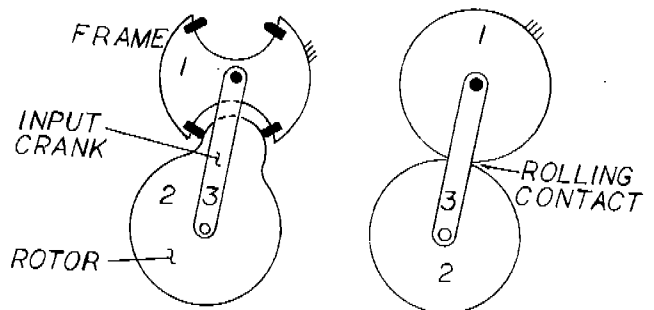


Figure 2d: Intermeshing engagement, external axis train and its driving gear

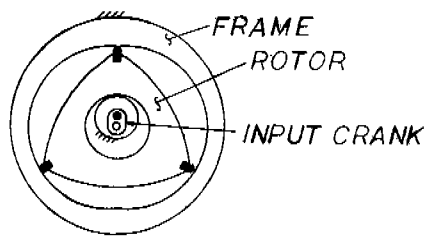


Figure 2e: Slip engagement, internal axis.

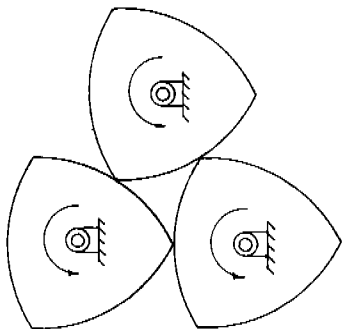


Figure 2f: Counter engagement.

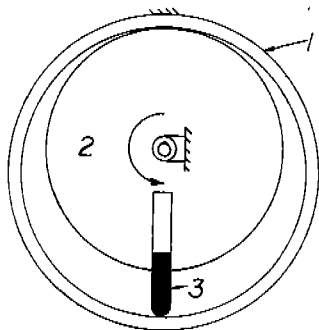


Figure 3a: Single vane rotary compressor.

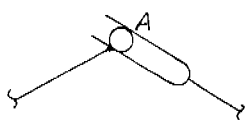


Figure 3b: Pin in slot.

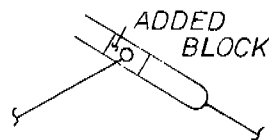


Figure 3c: Slider in slot.

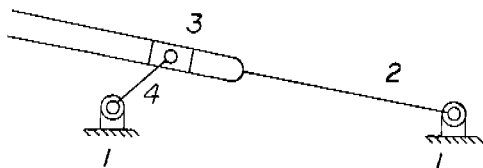


Figure 3d: Slider crank with the same generalized linkages as the single vane rotary compressor.

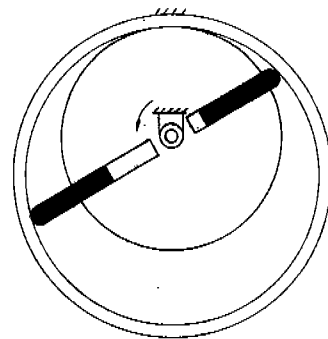


Figure 4a: Two vane rotary compressor.

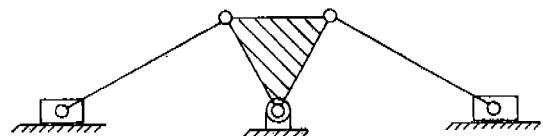


Figure 4b: Two piston pump with the same generalized linkage as the two vane rotary compressor.

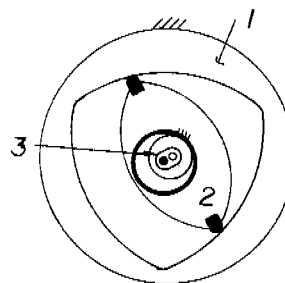


Figure 5a: Intermeshing engagement, internal axis pump.

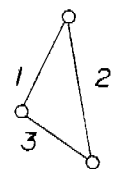


Figure 5b: Generalized linkage of the gear train

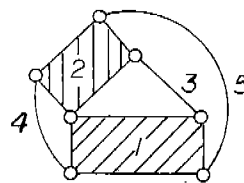


Figure 5c: Generalized linkage without the seals.

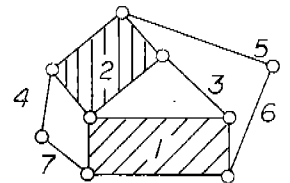


Figure 5d: Generalized linkage including the seals.

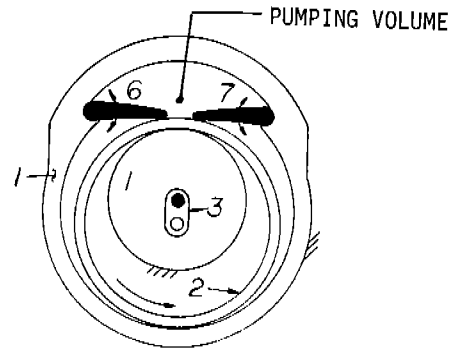
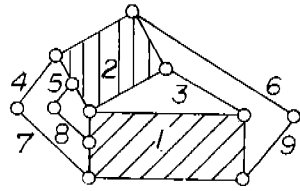
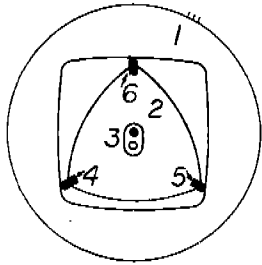


Figure 7b: Respecialized linkage.

Figure 6a: 4:3 Intermeshing engagement, internal axis pump/engine.

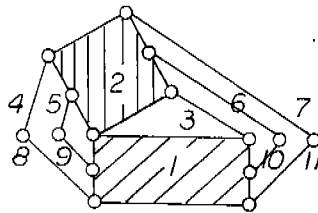


Figure 6d: Generalized linkage of 6a.

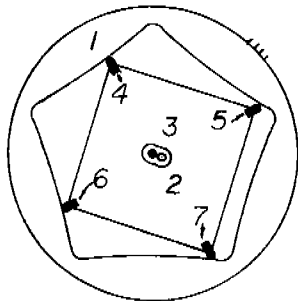


Figure 6c: 5:4 Intermeshing engagement internal, axis pump/engine.

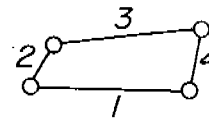


Figure 8a: Generalized linkage.

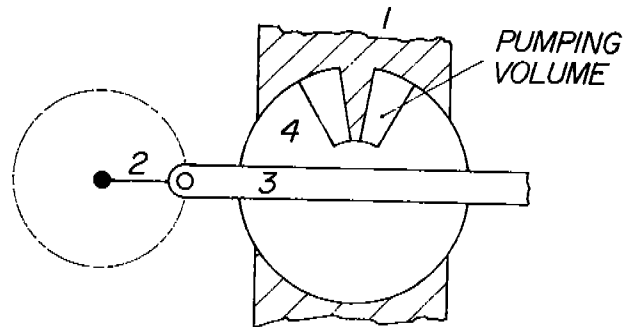


Figure 8b

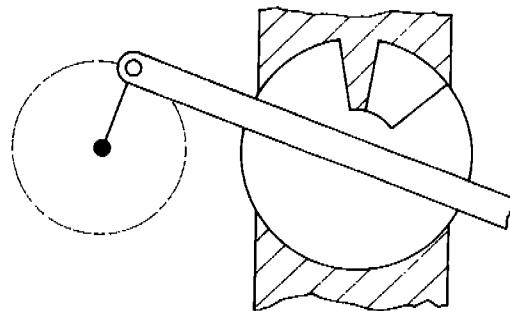


Figure 8c: Respecialized linkage.

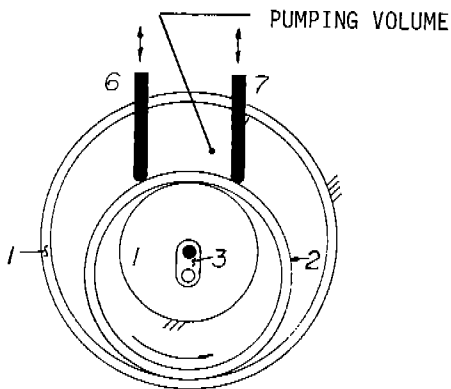


Figure 7a: Respecialized linkage.

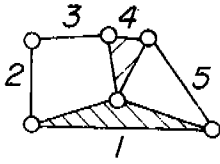


Figure 9a: Generalized linkage with zero degrees of freedom.

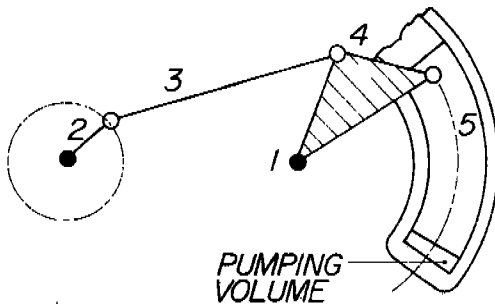


Figure 9b: Respecialized linkage.

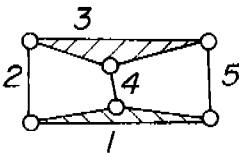


Figure 9c: Generalized linkage with zero degrees of freedom.

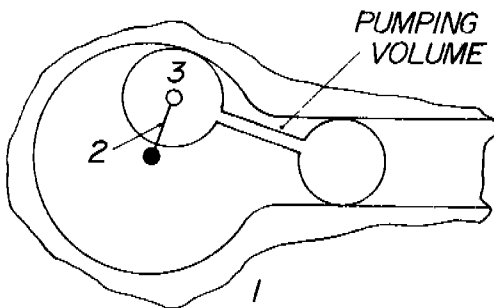


Figure 9d: Respecialized linkage.